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THESIS

ROUTE SURVEY PERIODICITY FOR MINE WARFARE

by

Hartwell F. Coke, V

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Thesis Advisor: Peter Chu
Second Reader: Ronald Betsch

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One of the Navy's most long standing challenges has been conquering the mine warfare threat. As mines and mine warfare techniques evolve and become more sophisticated, so does the United States' ability to counter the threat. The United States newest technique for countering a potential mined harbor, or route, is a process known as "change detection."

This concept uses previous side scan sonar images of the area prior to a mining event and compares those images to a recent scan post the mining event. This allows trained technicians to identify and classify previously recognized Non-Mine, Mine-Like Bottom Objects (NOMBOs) from new shapes present on the seafloor. The object of this classification is to reduce the number of hours searching and clearing previously existing objects that are thought to be mines. If the object or shape was present before the mining event, then it can be neglected from further inspection.

The challenge is having a sufficiently current scan of the area "on the shelf." The environmental bottom conditions of certain locations change dramatically more often than others. It is necessary to update more frequently scans of bottom regions that present large change rates than of areas that have smaller change rates.

This thesis will present a logical effort, based on known bottom conditions, to aid in determining the rate, or periodicity, at which certain regions should be surveyed in order to have a quality scan standing by. The Resurvey Integration Model (RIM) will provide a user friendly method to efficiently and effectively predict a reasonable periodicity interval of an area to support the Navy's Mine Warfare and Meteorology and Oceanography communities. Use of this model will stand to reduce unnecessary expenditure of assets, resources and time on areas that do not require as frequent of surveys. These up to date scans will in turn aid in expediting the clearing of routes, ports and harbors after a mining event.

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ROUTE SURVEY PERIODICITY FOR MINE WARFARE

Hartwell F. Coke, V
Lieutenant Commander, Unites States Navy
B.S., Virginia Polytechnic Institute and State University, 1995

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Author: Hartwell F. Coke, V

Approved by: Peter Chu
Thesis Advisor

Ronald Betsch
Second Reader

Jeffrey Paduan
Chairman, Department of Oceanography

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Finally, I would like to thank my family. To the love of my life, my wife, Cristin, whose constant caring and love kept me healthy and motivated to complete this task; to my son, Hart, whose arrival only inspired me more and rejuvenated my efforts; to my parents, who have dedicated their lives to loving and supporting unconditionally their children and grandchildren; and to my sister, Katie, who is a constant source of strength and guidance in all aspects of my life.

I am blessed with a wonderful family that has supported me throughout all my endeavors thus far in life. Not only was I fortunate enough to be born into a loving family, but I also was lucky enough to marry into one, as well. It is said that God looks after drunks, dummies and babies…maybe somehow cowboys have also found their way onto his list.

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I. INTRODUCTION

In the Navy, there exists a need for development of a comprehensive program designed to predict route survey periodicity. This idea is not new and has been attempted by various groups both in the United States (U.S.) and by U.S. allies. The fleet needs a common sense approach that will produce a reasonable estimation of how often surveys should be performed in locations here and abroad. Creating an alternative process in which to calculate the period of time that is reasonable between oceanographic surveys will be useful to the Mine Warfare (MIW) community. Military and civilian leaders charged with supplying the money and assets necessary to carry out these surveys will also benefit.

The approach should be based on science but also be easily understood by the operators in the fleet with whom the information is most useful. Also, commanders and civilians should be able to apply this model to various locations that possess vastly different environmental characteristics. In the event of a mining attack, not just military personnel become essential to the MIW operation, but also the civilian scientists working for the Naval Oceanographic Office (NAVOCEANO). The work conducted by these individuals can substantially decrease the time required for MIW assets to detect and classify potential mines on the seafloor.

There are four key parameters produced by the NAVOCEANO team that in combination can predict a survey periodicity assessment. These parameters are burial, clutter, roughness and sediment type. It is import to note that other factors will also be included in the model. All the factors are associated with the four key parameters and will help to drive the best solution.

A. HISTORY AND IMPORTANCE OF ROUTE SURVEY PERIODICITY

When speaking of mine warfare tactics in 2009, most Americans would not believe or consider sea mines to still be a threat to today's naval force. After all, the last

U.S. ship to be damaged by a mine happened 18 years ago. Considering all the new advanced weapons of the world, who would still use an old sea mine in aggression?

Despite the infrequency of water borne mine attacks, we should always remember that they are cheap and very effective way to disrupt, and in certain circumstances, defeat a more powerful opponent. During the Korean War in 1950, Rear Admiral Allan Smith stated, “we have lost command of the seas to a nation without a navy, using pre-World War I weapons, laid by vessels that were utilized at the time Christ” (Miller, 1994). He was referring to the use of sea mines and how they are capable of defeating a more powerful navy. Even today, sea mines have become much more advanced and constitute a substantial threat to the security of the U.S., both domestically and overseas.

Due in part to the effect sea mines have on damaging ships, there is a significant advantage to using mines, or simply claiming to have planted mines. This is especially true for a country with limited resources and a limited navy. A possible mining event in a strategic strait or harbor by a rogue state could damage the global economy within days depending on the location of the threat. The threat of a vessel being damaged by a mine would provoke insurance companies to disallow their insured commercial vessels to sail in the vicinity of the threatened strait or harbor. The economic consequence, especially of crude oil, would be devastating to both the supplier and the receiving group. Additionally, finding a modern day Commanding Officer (CO) of a warship willing to follow in the footsteps of Admiral Farragut, in 1864, shouting, “Damn the torpedoes…go ahead…full speed!” would be a challenge as well (Farragut, 1879). The CO would avoid the area at all cost unless ordered to enter by his superior. The U.S. Navy still maintains a fleet of Mine Countermeasure ships, dedicated MIW helicopters and Explosive Ordnance Disposal teams to combat the consistently advancing sea mine threat.

These groups, with the help of technology, have made huge strides in the ability to conduct mine warfare hunting and clearing operations in an expeditious manner. With the combination of well trained technicians and state of the art equipment, the mine warfare fleet can conduct operations anywhere in the world and provide a commander with specific time verses risk analysis of the mine threatened area. As with most all necessary assets, these come with a cost.

The two main factors in MIW are time and risk. When conducting MIW operations, a commander must be concerned with the factor of time. As the world's oceans have become crucial to the stability of the world economy, today more than ever it is important to protect and defend the developed shipping lanes. If a commander requires the lowest amount of risk to his fleet passing through the mine area, then he will have to allow for additional time for the mine clearing operations to take place. If he is willing to accept a reasonable amount of risk to his ships, then the time required to clear will drop substantially. It is important to note that typically with a large mine threat area, the chance of having 0 risk is virtually nonexistent. Even after the most exhaustive clearing efforts, there will always be a slight chance that the MIW assets may have "missed one or two" depending on time allotted.

The time constraint on mine detection and classification has become critical in the fight against countries or rogue states that may utilize mining as an attack or deterrence. Current efforts are underway to map the bottom of the ocean in locations of strategic importance. Numerous Sea Lines of Communication (SLOC) are considered high priority, as these are lines that allow commerce to exchange from country to country. These SLOCs also play a crucial role in allowing warships to transit quickly and efficiently in order to get on station in various regions around the globe. If a mining event occurred in the Suez Canal for example, then numerous vessels, both commercial and military would not be allowed to pass until the area was "cleared" of mines. The canal is a strategic SLOC allowing some 20,000 ships yearly to save time by transiting the canal (Suez Canal Authority, 2009).

The Strait of Hormuz is another SLOC of strategic importance. This strait is the only path for vessels in or out of the Arabian Gulf. Tremendous amounts of petroleum pass through this strait daily and a disruption to this flow could be devastating to the world's economy. This strait is also of strategic importance allowing warships to enter into the region where arguably foreign involvement is necessary to the stability of the region.

Several countries have the capability of causing disruptions in the SLOCs and/or harbors of strategic importance. Some fifty countries now have mining capabilities and

are in a position to readily deploy sea mines (Ocean Studies Board, National Research Council, 2000). The threat of sea mining is just as important today as it was 140 years ago during Admiral Farragut's time.

B. CLASSIFICATIONS OF SEA MINES

There are three basic types of sea mines. The first is free floating mines known as drifting mines, which float at the surface. These mines can sometimes be seen from lookouts on ships provided the water surface is smooth. These mines are generally actuated by contact with another object (i.e., a ship). Drifting mines are totally at the mercy of the surface currents and once deployed, have no "allegiance" to the deploying force. The second type is bottom mines. These mines are placed on the bottom (seafloor), as the name implies, and are generally actuated by one or more of the following ways: pressure, magnetic, acoustic, seismic, or some combination of these. Once laid, the deploying force can maintain a certain level of positive control over bottom mines unlike the drifters. The third basic type of mines is moored mine. This type has an anchor on the ocean bottom attached by a tether. The explosive portion of the mine floats up in the water column and can have the same actuation devices as the bottom mines to include contact actuation.

Figure 1 illustrates the mine threat area based on mine type and water depth.

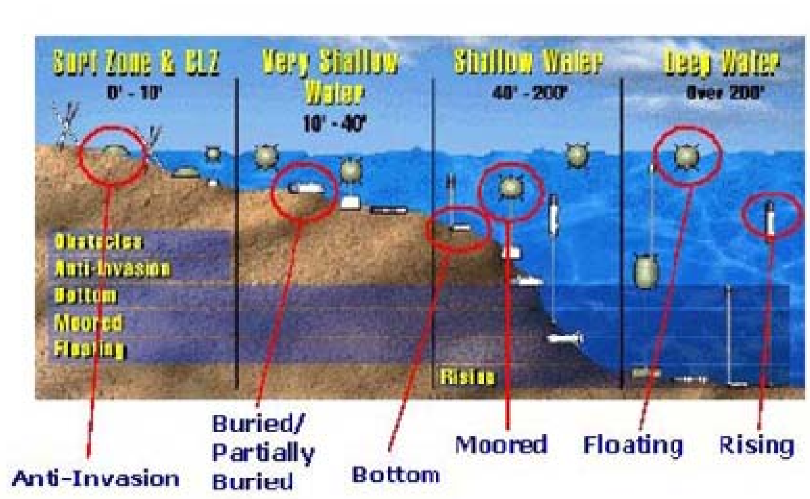

Figure 1. The mine type, depth, environment and characteristic (From Department of the Navy [NMWP], 2000)

The actuation methods for mines have become extensively more advanced than when David Bushnell invented the first drifter back in 1776 to attack the British. The advances in force of detonation, firing mechanism sensitivities, arming delays and ship counters all make for a challenging threat for Naval forces to counter.

As advancements in mines have increased, so has U.S. technology to detect, classify and destroy the mines. The U.S. advances have also taken the form of protecting ships by utilizing magnetic and acoustic silencing. Deperming cribs were developed to reduce the ships permanent magnetic signature. In addition, ships are built with degaussing systems onboard to reduce the ships induced magnetic field caused by it's location on the Earth. Most all ships in the U.S. fleet have Prairie, Masker, forward lookouts and a Quiet Ship Bill in order to reduce the ship's acoustic signature and chances of striking a floating mine. These advancements do aid ships in the fight against actuating a sea mine.

C. THE CONCEPT OF CHANGE DETECTION

The concept of "Change Detection" has been developed as a solution to help reduce the time required to detect, classify and neutralize potential mine threats. This enables a more efficient reopening of threatened harbors or routes that are important to trade, without an increase of risk to ships.

This change detect process requires construction of an extremely detailed seafloor chart of the SLOCs, harbors or Area of Interest (AOI). As bottom surveys of areas are completed and processed, the enhanced bottom images can be stored in a database for future use. Any suspected mine threats can be investigated after completion of the initial survey. If a potential mining event was to occur, then the MIW commander could use assets to gather a "new look" at the bottom. The new scan could then be compared to the most current previous scan. This comparison would show which objects are "new" on the bottom as opposed to what has been there all along (prior to the mining event). This narrows down the number of Non-Mine, Mine-Like Bottom Objects (NOMBO) to be investigated by follow-on assets. "A capability for detection of change may offer

significant improvements in operational time lines by allowing MCM forces to quickly discount previously mapped NOMBO" (Ocean Studies Board, National Research Council, 2000).

Due to constantly changing environmental characteristics of the seafloor and the continuous addition of manmade debris showing up on the bottom, the best case scenario would be to survey every location once a year. However, with limited resources, determining how often is "good enough" to maintain a survey becomes as challenging as the mine warfare threat itself.

It is important to point out at this point that the idea of change detection does not apply to contact mines. The two types that are subject to the advantages of change detection are bottom and moored mines. Thus, for the remainder of this thesis, when discussing sea mines, the author will only be referring to bottom or moored mines.

1. Sonar Systems

Both the MIW fleet and the Navy's Oceanography community are utilized in scanning the bottom. In order to gather an accurate image of the bottom, an advanced sonar system is required. Currently, NAVOCEANO survey ships are conducting the greatest amount of survey work for the MIW effort. Those resources are currently at max utilization with the MIW work being of high priority. The survey ships use the Klein 5000 side scan sonar as their primary workhorse.

The Mine Countermeasure (MCM) Avenger class ships also do survey work. However, despite the MCMs being Klein tow capable, they typically use their organic sonar, which is the AN/SQQ 32. Unfortunately, the AN/SQQ 32 recordings are currently not used by NAVO to generate finished MIW products. The AN/SQQ 32 also does not have the high resolution of the Klein 5000.

a. The AN/SQQ-32

The SQQ-32 mine hunting sonar was developed by Raytheon and is used primarily on MCM class ships. These ships are capable of locating, classifying and if necessary, neutralizing both moored and bottom mines. To enable this type of

responsibility, the ships rely heavily on the capability of the SQQ-32. Its active sonar allows for detection of objects not only on the bottom but also in the water column (Federation of American Scientists, 2009). Currently, the data received from the SQQ-32 is not considered in the classification of burial, clutter, roughness and sediments conducted by NAVOCEANO.

b. **Klein 5000**

The Klein 5000 side scan sonar was developed by L3 Communications for military and commercial use. The Klein 5000 is approximately 2 meters long and weighs 155 lbs. The Klein uses multibeams at a frequency of 455 KHz to map the seafloor. The system allows for complete seafloor coverage of the survey area each swath will overlap. The newest Klein allows for tow speeds of up to 10 knots (L3 Communications, Klein Associates, Inc., 2009). This enables the survey vessels to spend less time at sea surveying which in turn saves money. The Klein data is what allows NAVOCEANO to classify clutter and roughness based on the mosaics.

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II. MINE WARFARE SURVEY

A. WHY SURVEY?

By far, one of the best advancements in fighting a mine threat is the ability to clearly "see" the bottom. As discussed in the introduction, an important aspect of conducting survey operations in high traffic areas and ship routes is to expedite mine hunting and neutralization activities at a future date. Survey technology and techniques allow the side-scan sonar technicians to compare a previous bottom image with a current image of the same area. This allows for easy visual recognition of changes in the seafloor. Certain bottom characteristics play a major role in how effectively the technician can "see" the bottom to conduct the comparison. Those characteristics or parameters will be discussed in a later chapter.

The most current survey image should be obtained just after the mining event has taken place. The critical piece then becomes the date of the last survey conducted of the area. The older the previous survey, the greater the chance that more bottom parameters have changed, thus requiring more time to be exhausted in eliminating non-threats. The question becomes, what is a reasonable amount of time to allow between surveys of a particular area? This question has been discussed and studied for several years and by several countries.

The primary countries developing a method to predict route survey periodicity are the U.S. and the United Kingdom (UK). Both of these countries have dedicated ships tasked with conducting complete bottom surveys. The U.S. uses a fleet of hydrographic survey ships identified by the T-AGS letter identifier. Ships such as USNS PATHFINDER (T-AGS 60) or USNS HENSON (T-AGS 63) have conducted hundreds of bottom surveys supplying the information to the Naval Oceanographic Office database. The technicians at NAVOCEANO process and evaluate survey data collected by these survey ships.

The UK also has several hydrographic survey vessels conducting similar bottom surveys. Two of these survey ships are HMS ECHO (H87) and HMS ENTERPRISE (H88). The UK survey fleet supplies data back to the United Kingdom Hydrographic Office (UKHO). The UKHO has a staff of technicians who evaluate the survey data in a similar fashion as NAVOCEANO. The UKHO produced a periodicity model and conducted a Mine Warfare Route Survey Maintenance Report in June of 2005 (Armishaw, 2005).

B. UKHO MODEL

1. Benefits and Usefulness

The UKHO model is designed to ingest environmental features and sonar data collected during surveys. The goal of the UKHO Maritime Environment Information Centre (MEIC) was to provide guidance on the route survey maintenance program. The model produces recommended resurvey intervals for the different priority routes utilized by the UK.

2. Why not use the UKHO Model in this Study?

The UKHO model has some benefit and several concepts were referenced in the completion of this thesis. However, the model was designed to perform in the vicinity of the UK taking into account local knowledge and intelligence. To accurately apply this model, based on the portion we received, to other locations around the globe would prove ineffective. The declassification of the UKHO model rendered it of little or no use to locations outside the UK, though the model principles do appear to be worthy of further study and investigation.

C. AREAS OF STUDY

In selecting the areas of study, several factors were used. The first was the availability of consecutive survey data. The next factor was bottom composition and

texture. The third was strategic importance to the Department of the Navy (DoN). The final factor was potential density of traffic utilizing the area.

1. Norfolk Naval Operating Base

A portion of the approach to the Norfolk Naval Operating Base found in Norfolk, Virginia was selected as a near shore, shallow water area with substantial coastal and riverine interactions. This was also selected based on the availability of consecutive surveys conducted by NOAA for use by the Department of Homeland Defense (DHS). Figure 2 illustrates the location of the survey area used in this thesis.

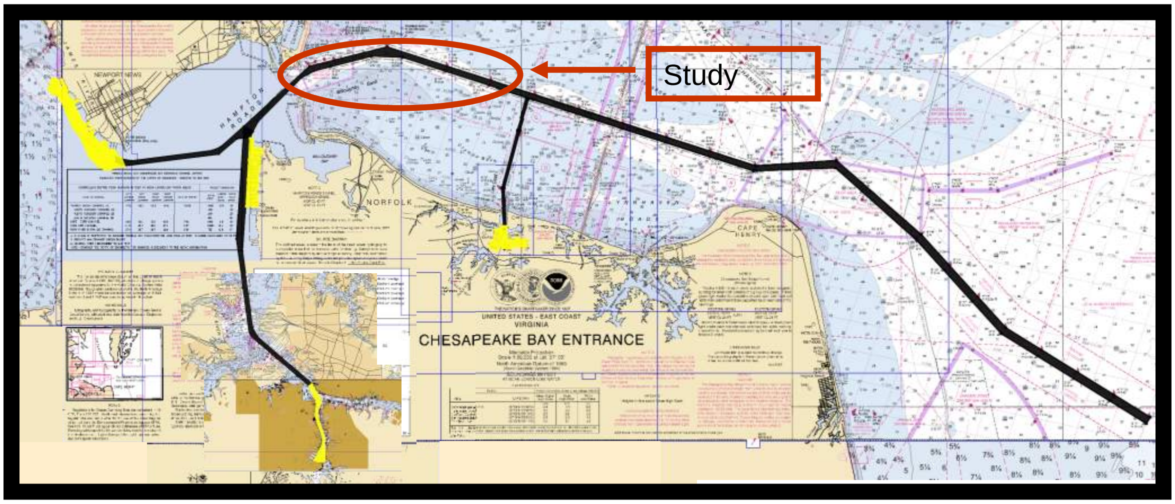

Figure 2. Depicts area of survey study approaching Norfolk Harbor. Route indications provided by Naval Oceanographic Office (After Thompson, 2008)

Norfolk provided a prime location for study as the approaches to the harbor pass through the southern end of the Chesapeake Bay. There are several rivers influencing not only sediment flow and quantities, but also density variations (freshwater) and water levels. The bottom composition of the southern bay ranges from sand to coarse silt and is predominantly caused by shoreline and ocean input (Langland and Cronin, 2003).

The general circulation pattern of the bay is common to many estuaries. The pattern is established by landward flowing dense seawater under less dense surface

freshwater flowing towards the ocean. Figure 3 is an illustration of partially mixed estuaries similar to the southern end of the Chesapeake Bay.

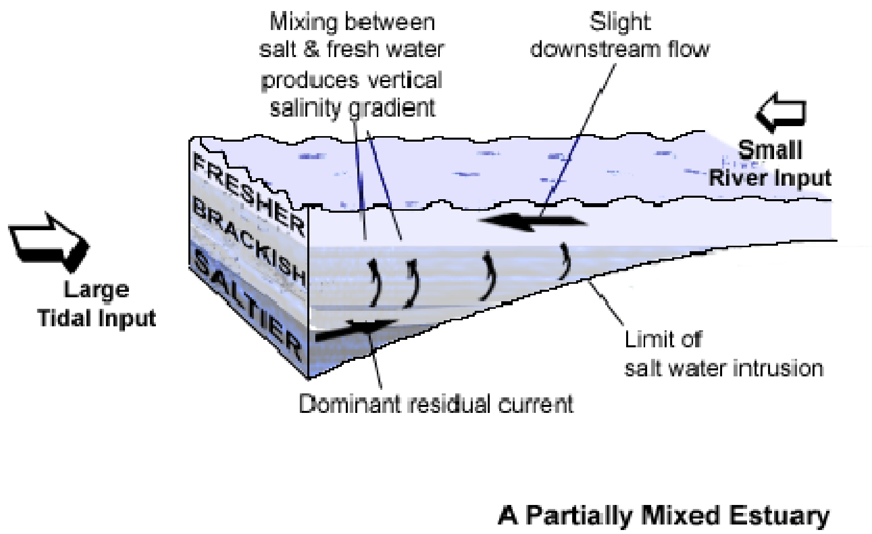

Figure 3. Illustration of the circulation pattern associated with a partially mixed estuary like the Chesapeake Bay (From Chemgapedia, 2009)

As is typical, wind driven waves and tidal currents also contribute to the complexity of the lower bay circulation pattern. Near surface current speeds in the southern bay are >10 cm/s, while near bottom speeds average ~5 cm/s. The bottom currents tend to be 90 degrees out of phase with the surface currents (Wang, 1975).

In selecting areas, it was of importance to attempt to find areas that did not have the exact same bottom sediment type or similar environmental characteristics as this would help shape the development of a new periodicity model. Environmental characteristics play a crucial role in determining how mine operations are to be carried out. Using surveys from non-similar environmental areas would allow for a better determination in the final results of the model.

The final reason for selecting Norfolk is its tremendous strategic value for the DON as the Norfolk Naval Operating Base is considered the world's largest naval base. Maintaining the security of the approaches, and harbor itself, are crucial to the

availability of the assets stationed at the base. Norfolk is used by numerous warships and also has a large amount of commercial shipping traffic. This location will serve well for continued study in the area of MIW.

2. Arabian Gulf

See Classified Appendix for further information.

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III. PARAMETERS

It is necessary to describe these factors that affect the seafloor and survey requirement. Factors such as tidal flow, bottom and surface currents, bottom type, amount of debris found on the bottom, number of fishing vessels working in the area, and the number of merchant vessels passing over the area are all critical in determining the need to survey or resurvey. To incorporate all the environmental factors, both manmade and natural, into a model capable of determining a survey periodicity is a daunting task. However, the need to initially survey and to determine what needs surveying is an easy question to answer. Any SLOC or harbor that is of strategic importance, no matter how small, should be surveyed and the data placed in an accessible database. It is vitally important for the U.S. Navy to maintain a fleet of survey ships that can be deployed to any location necessary. There is always a need to gain knowledge of the oceanographic characteristics of a route or harbor. U.S. ships, whether during wartime or for humanitarian assistance, will always need accurate charts to use when transiting into various locations. In order to obtain accurate charts, surveys must be conducted.

Simplifying the numerous factors affecting the seafloor requires an understanding of how each parameter can contribute to the overall appearance and transformation of the ocean bottom. These environmental factors can be reasonably accounted for in four key parameters that are produced quantitatively by NAVOCEANO once the survey data has been examined. The parameters found in section A are derived from survey data by the technicians at NAVOCEANO. These four parameters represent the bulk of the survey data that supports the MIW mission. Section B will have additional parameters that help support the changes found in the four key parameters. All of these will be discussed from a MIW point of reference.

A. KEY PARAMETERS USED IN THE MODEL

1. Burial

Burial, with respect to MIW, is defined by the amount of coverage a particular mine may develop once it interacts with the seafloor. This measurement is done by calculating the percent that the object is buried. The bottom type has a critical role as one would not expect a mine to become buried on a rock bottom. However, a sand or mud bottom may allow for near 100% burial of a mine. Sediment strength along with the consolidation and water content help determine the how much burial may occur.

Burial is broken down into two additional types. The first is impact, which is the result of the mine coming to rest on the bottom once it has been deployed. The second is subsequent, which is caused by currents interacting with the bottom. This is known as scour and can make locating a bottom mine extremely difficult.

The categories of burial are found in Table 1. These are adopted from NWP 3-15.41 and published by NAVOCEANO in their "Guide to NAVOCEANO Sediment Databases, Sediment Classifications, and Mine Warfare Bottom Properties" (Naval Oceanographic Office, 2009).

BURIAL		
BOTTOM TYPE	NUMBER	PERCENT BURIAL
Rock	1	0%
Mud or Sand	2	>0% to ≤10%
Mud or Sand	3	>10% to ≤20%
Mud or Sand	4	>20% to ≤75%
Mud or Sand	5	>75% to ≤100%

Table 1. Burial categories derived from NWP 3–15.41

By studying the changes in impact and subsequent burial, a basic prediction can be made regarding bottom currents along with the effects of surface current and tidal influence. Typically, the category of subsequent burial is not provided but can be derived

based on comparison between two surveys of the same area taken at different times. The effects of velocity components (U and V) will manifest in the degree of scour influencing the burial of an object over time. These same bottom currents can also be associated with uncovering an object as well. This particular parameter is tied closely to the sediments parameter as typically sand will encourage more scour than mud or rock.

See attached Classified Appendix for further information.

2. Clutter

Clutter is defined by the number of NOMBOs per square nautical mile. It is important to note that bottom contacts, which are not identified by other means than side scan sonar are considered Mine-Like Contacts (MILCOs). Simply detecting and classifying the object does not make it a NOMBO. It must also be identified as not a mine, which requires a certain degree of investigation.

The measurements for clutter are located in the chart below.

CLUTTER		
CATEGORY	DESCRIPTION	NOMBO/sq nm
1	Low	<15
2	Medium	$\geq$15 to $\leq$40
3	High	>40

Table 2. Clutter categories derived from NWP 3-15.41

Clutter can come in the form of natural occurring coral or rock outcrops on the seafloor. Clutter also accounts for all the manmade objects that are placed on the bottom either deliberately by humans or due to an act of nature such as a hurricane or flood. The increase in clutter on the bottom makes the MIW problem more challenging. It requires a great deal of time to investigate each potential mine threat that may exist on the bottom. The side scan imagery has become more advanced over the years, but still leaves room for interpretation. A well trained technician uses clues from the image to help determine what is mine like and what is not. The more clutter that is present, the more intensive this

task becomes. The primary variation in this parameter is from manmade debris. Therefore, it becomes necessary to incorporate additional factors such as the amount of vessel traffic over the area and whether or not a hurricane passed over the area. Both of these factors can dramatically change the amount of debris on the seafloor. If the vessel density increases or decreases during the period, then this information needs to be accounted for in the periodicity calculation. Also, the concept of a natural anomaly occurring during the years between surveys must also be included to produce a most accurate solution. Both of these factors will be discussed in greater detail in the next section.

3. Roughness

Roughness is defined by a measure of ridge height along the seafloor. The roughness parameter indicates how disturbed the bottom seafloor texture is and to what extent it could preclude technicians from observing a mine or NOMBO. A sand bottom that is influenced by strong near bottom currents could potentially produce ridges or smooth pre-existing mounds. In the case of ridge development, this function would potentially produce shadow zones blocking out possible mine threats. If the environmental conditions were to smooth the seafloor then the mine detection and classification operation would be much easier.

The roughness parameter has three categories and the descriptions are found in Table 3.

ROUGHNESS		
%/CATEGORY	DESCRIPTION	HEIGHT, (M)
(<5) 1	Smooth	<0.2
(5 to 15) 2	Moderate	≥0.2 to ≤0.3
(>15) 3	Rough	>0.3

Table 3. Roughness categories derived from NWP 3-15.41

The roughness parameter, in concert with burial, provides additional insight necessary to discern the effects of the bottom velocities as well as the surface and tidal influence on the particular area of interest. This is a crucial aid in determining the

periodicity and all but eliminates the necessity to scientifically measure these currents across the entire span of the survey area using equipment such as the Acoustic Doppler Current Profiler (ADCP). With the use of these two parameters, it is easy to judge the strength or weakness of the oceanographic environmental influences to a reasonable determination.

4. Sediments

Bottom type and composition contributes significantly to levels of burial, clutter and roughness. In the "Guide to NAVOCEANO Sediment Databases, Sediment Classifications, and Mine Warfare Bottom Properties," NAVOCEANO provides basic "rules of thumb" in interpreting the impact of each of the three categories above by the type of sediment found. NAVOCEANO points out that these rules of thumb are useful, but provide nothing more than an approximation, which is always subject to uncertainty (Naval Oceanographic Office, 2009).

The U.S. MIW planning guide (NWP 3-15.41) designates a table that correlates three of the four parameters. This table provides a basic relationship between sediments, burial and roughness by individual categories. A distinct bottom category letter can be deduced by relating these three key parameters. This letter designates how challenging the bottom may be for MCM operations. The table also provides some insight into how each parameter's specific category ties into the overall bottom classification. As the letters move from A-D, the complexity of the bottom increases. Thus, a D bottom is much more difficult to detect and classify mines than an A type bottom.

BOTTOM COMPOSITION	PREDICTED MINE CASE BURIAL	BOTTOM PROFILE GROUP	BOTTOM CATEGORY
MUD OR SAND	0 to 10	SMOOTH	A
		MODERATE	B
		ROUGH	C
	10 to 20	SMOOTH	B
		MODERATE	B
		ROUGH	C
	20 to 75	SMOOTH	B
		MODERATE	C
		ROUGH	C
	75 to 100	ALL	D
ROCK	0	SMOOTH	B
		MODERATE	C
		ROUGH	C

Table 4. Bottom Composition, Burial and Roughness used to derive a Bottom Category Classification

The thickness of the bottom sediment type, plus the magnitude of the bottom currents, is responsible for determining the burial of an object. It is understood that just because there exists strong bottom currents, and a sand bottom type, there may or may not be potential for burial and bottom roughness changes. An object could become more or less buried and the roughness could increase or decrease. It is this uncertain dynamic that makes the survey comparison of the four parameters a better determination of how often a survey should be conducted.

B. ADDITIONAL PARAMETERS USED IN THE MODEL

1. Vessel Traffic

Vessel traffic is simply the amount of ships passing over a particular point on the seafloor as measured per month by the Historical Temporal Shipping (HITS) model. A yearly average can then be extrapolated from the data. This model will be discussed in more detail in a later section. The amount of ship traffic passing over a particular route or utilizing a harbor can be a critical addition in the determination of clutter on the seafloor. Large amounts of traffic passing over an area can lead to substantial changes to the amount of debris located on the bottom.

It is important to understand changes in vessel density in order to predict a consistent survey periodicity. As vessel traffic increases, so should survey periodicity due to the potential increase of clutter. Therefore this parameter is an addition in the model and can add weight to the clutter index. The original clutter factor, as formulated from the survey comparison will account for the majority of changes, but if a harbor or route becomes more or less utilized it may offset the timing of the next survey.

2. Fishing Density

Fishing density is the number of fishing vessels per year transiting the survey area. This number is critical because certain fishing techniques can have a large impact on the seafloor. The HITS model has a category called "fishing" and it will give monthly densities of fishing vessels. However, this does not represent a breakdown of types of fishing vessel, which would be much more beneficial for a route survey periodicity application.

Fishing can be broken down by method into several categories. Gillnetting, trolling, trawling, dragging, dredging, traps/pots are all various methods to catch fish. Several of these fishing techniques do not cause a dramatic change on the seafloor, other than by increasing the amount of debris found on the bottom. However, three of these techniques can cause enormous amounts of damage to the seafloor, with regard to MIW operations. These three are trawling, dredging and trapping. Trawling and dredging contribute the most to large areas of seafloor damage. The use of traps, or pots will add to the amount of clutter on the bottom and can make the classification/investigation timeframe much longer, but they typically do not cause the wide spread damage as that of the other two.

a. Trawling

Trawling consist of towing a large cone-shaped net by one boat, or two through the water column. The range of depths that the net can be trawled is between the surface and approximately 2 km. Surface trawling and mid column trawling do not cause substantial damage to the seafloor, unlike bottom trawling. Bottom trawling can cause

significant damage to the seafloor due to the net skimming across the bottom. The trawling speed which dictates the speed at which the net flows across the bottom can be as high as 7 knots (Food and Agriculture Organization, 2009). Figure 4 depicts images of commonly used bottom trawls.

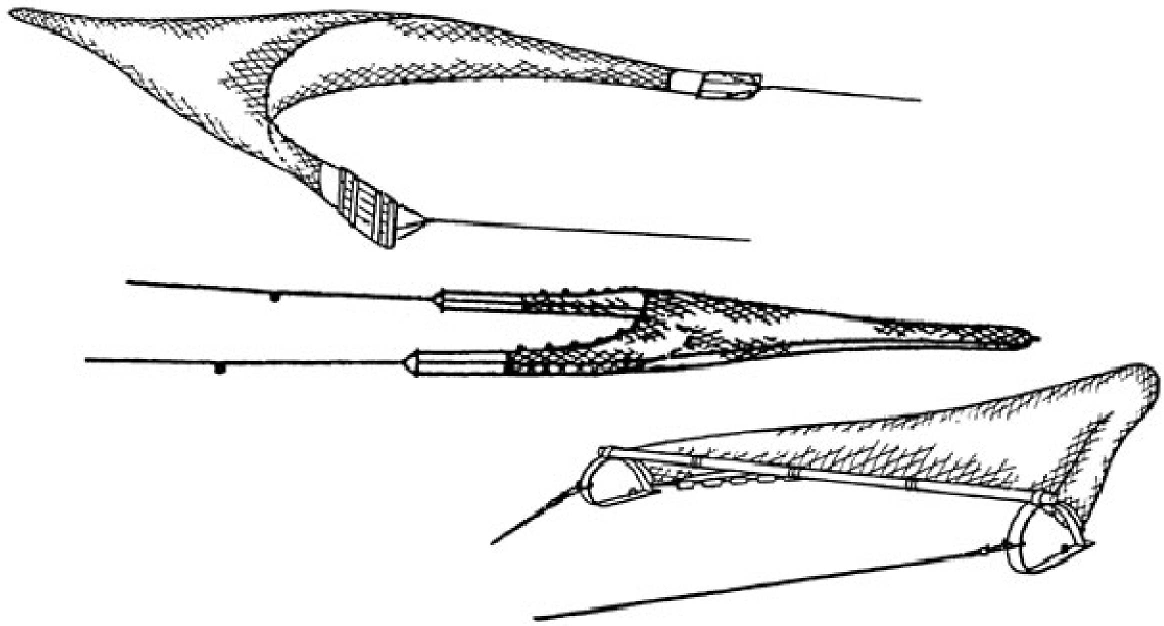

Figure 4. Bottom trawls designed to catch species on or near the bottom of the ocean (From Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, 2009)

Bottom trawling, performed correctly, requires contact with the bottom. This means that there is not only an induced current caused by the moving net, but also an additional physical degradation of the bottom. This degradation can cause changes in locations of previously classified bottom objects or can disrupt the bottom sediments to allow for increases in burial characteristics. These side effects of trawling will increase the time required to conduct change detection. They will also cause unnatural changes to the bottom characteristics between surveys. The natural process of tidal flow and effect of currents on the bottom will be altered dramatically, if the area has been trawled.

b. Dredging

The second technique known as dredging involves towing a heavy metal frame with a mesh bag attached along the bottom of the seafloor. Certain dredges have metal points extending down that act as teeth biting into the seabed. This process helps to stir up the shellfish aiding in there catch. Figure 5 illustrates the types of dredges used to drag along the seafloor.

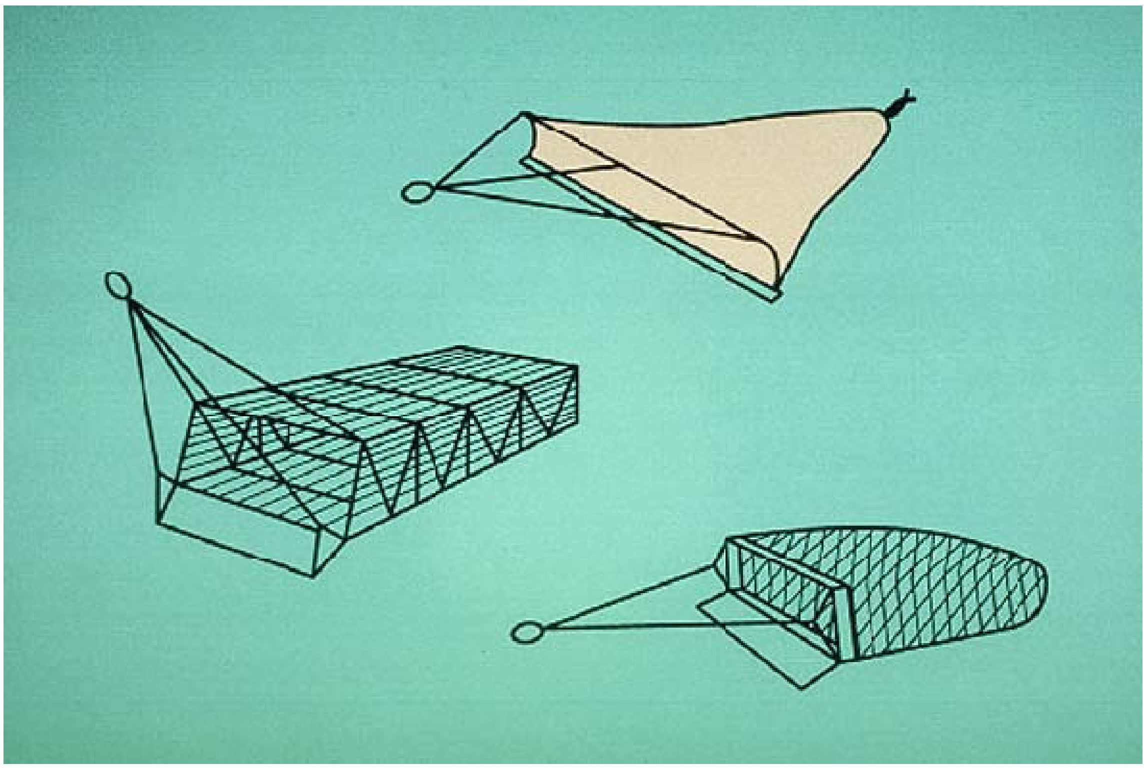

Figure 5. Dredges designed to drag along the ocean floor to catch shellfish (From Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, 2009)

Regarding MIW operations, this fishing technique, similar to trawling, can alter the seafloor by disrupting locations of previously placed objects. This will add more time to the change detection process as an object previously identified as a NOMBO will possibly be moved requiring assets to once again investigate the same object in a new location.

The roughness parameter is also affected by the dredge. Numerous studies have been conducted to determine the amount of damage caused by dredges to the seafloor. Eleftheriou and Robertson (1992) studied the effects of scallop dredging in a Scottish loch. They found significant physical changes to the seafloor caused by the dredges. Also, a study conducted by Thrush et al. (1995) in New Zealand found similar results after a dredge was pulled across the bottom of a bay. The natural ripples and topography of the bottom are completely broken down by the dredge. Normal tidal and bottom current action can cause these characteristics to return, but it may take as long as several years.

The reduction of ripples and bottom surface features does aid in the MIW problem. However, the dredge boxes leave large mounds on both sides which may increase the shadow effects from the side scan. This will degrade the MIW effort by increasing the masking of certain objects from detection. Depending on bottom type, the process of dredging can disturb the bottom sediment, allowing the tidal action to speed up or slow down the process of establishing ripples or covering (burial) objects. These anthropogenic changes can cause an error in the outcome of the model if not taken into account.

c. Traps and Pots

The third fishing method that can lead to additional objects on the bottom, involves using traps or pots. This method is usually designed to catch creatures on the seafloor such as crabs or lobsters. These large steel cages litter the seafloor. If the buoy that marks the pot gets separated from the line, then the pot remains on the bottom. Although this is an infrequent occurrence, it will contribute to the congestion of NOMBOs on the seafloor. Figure 6 depicts the types of traps and pots that typically add to the manmade debris on the ocean seafloor.

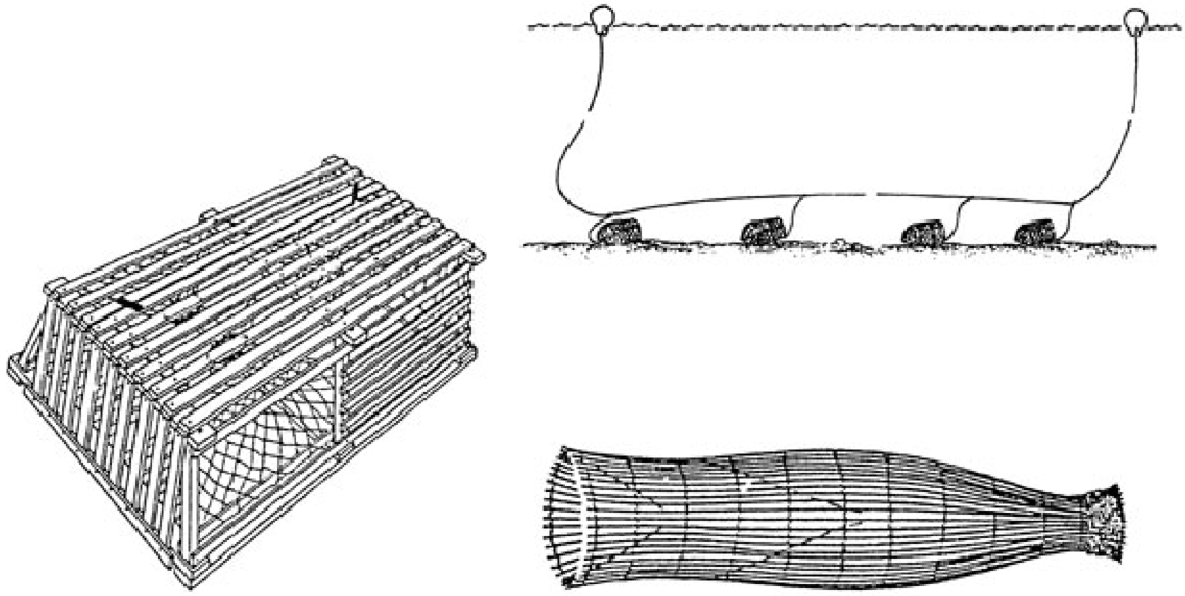

Figure 6. Traps and Pots used to set on the bottom allowing fish or shellfish to enter voluntarily but not escape (From Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, 2009)

It is important to consider overall fishing density, due to the effect it will have on the amount of clutter. The HITS data base allows for the input of a fishing only category. It would be difficult to asses the specific amounts of trawlers, trappers and dredgers yearly in order to obtain a more useful fishing density measurement. For the purposes of this model, the category will not be separated further as the specific information is not available.

In more recent years, the act of trawling has been banned from the coastal areas of the U.S. Dredging and trapping still take place and occur in more shallow regions. The majority of port surveys will have dredging and trapping interference. The deeper offshore routes will be subject to all three types of destructive fishing methods.

Aside from the obvious seafloor impact of the fishing method, the increase in number of vessels passing over the particular survey area only increases the chance for additional debris to appear on the bottom. This will drive up the amount of clutter which in turn will increase the need to survey the area more frequently.

3. Technology Changes

Technology development or improvement is a critical factor in the process of the model because the time between surveys also allows for advancements in technology. In this particular area, the improvements are typically tied to how well the bottom objects are made visible. In general, a less than five-year span will not generate too great a difference in the technology of available equipment and therefore no compensation is required. However, if the amount of time between surveys is large (>15 years) then attempting to compare changes between two surveys of the same area would be extremely difficult. The side-scan sonar equipment and computing capabilities tend to steadily improve, although not on a linear scale. Thus, for the purposes of this model the input has been broken down into three groups. The first category is for surveys that are conducted less than five years apart. This category can be neglected as potentially both surveys were completed with similar enough technology. If the surveys conducted are separated by more than five years but less than 15, then a 10% weight is added to both burial and clutter. This will help the model account for the changes in equipment ability and in turn produce a more immediate need for resurvey. The last category is for surveys that are conducted with greater than 15 year frequencies, which induce a weight of 25% to both burial and clutter. This method provides the model the means necessary to expedite a resurvey now option based on the time span between comparisons and the variation in equipment used to designate the bottom characteristics. For additional information regarding technology advances, please refer to the classified appendix.

4. Water Depth

Water depth is another crucial detail of necessary model information. The water depth can provide some insight into what effects the tidal flow and surface currents may play in the seafloor characteristics. Also, water depth can be a limiting factor as to what types of fishing vessels may be working in the area. The final important detail collected from knowing the water depth is the types of mines that may be encountered in the region.

In examining the survey areas, there is a range of water depth per survey. However, in determining water depth for the purposes of this thesis, the maximum depth at each survey location was selected. The reason for this is due to the likelihood of encountering a specific mine threat capable of causing mission abort damage to a ship along the survey route. For a more thorough discussion of this section, please see the classified appendix.

5. Uncommon Anomaly (Hurricane/Cyclone or Tsunami Passage)

Another important factor to account for is whether strong events (hurricane\cyclone or tsunami) have occurred during the period between surveys. The importance of this can not be under-estimated especially considering the current concern for certain types of climatologically changes. For instance, if a hurricane’s eye passed within 50 nautical miles of the survey location between survey periods and the survey location was within five nautical miles of land, the resulting resurvey index could be clouded. This is because the change between surveys would produce a false higher percentage in both burial and clutter depending on the water depth and vicinity to shore, respectfully. Neglecting to take this information into account could cause the model to calculate a higher than necessary resurvey plan.

A good example of why this consideration is so important would be to consider Galveston Bay, Texas post-September 2008. In September of 2008, Hurricane Ike made landfall as a Category 2 storm, directly impacting Galveston. This particular hurricane was exceptionally large in diameter and had hurricane-force winds that reached 115 miles from the center (Goddard Space Flight Center, 2009). It is reasonable to assume that most Category 2 or greater storms will have hurricane force winds (Winds > 74 mph) out from the center to at least 50 nautical miles. This factor will help keep the model from calculating a higher index number than required.

Additionally, Galveston Bay has become littered with debris from the hurricane. The Texas General Land Office has spotted almost 600 large objects in Galveston Bay after only surveying approximately one-fifth of the some 600-square-mile area (Tresaugue, 2009). A storm like Hurricane Ike obviously brings an impressive storm

surge that generally pushes debris from the coast inland. However, the retreat of the storm surge can also help litter the coastline as debris washes out to sea and sinks. This is also a factor as the storm moves inland dumping large amounts of rain that in turn will cause flooding as the water seeks return to the ocean.

The amount of sediment that is deposited after a hurricane or tsunami also complicates the resurvey index. Even a tropical storm can cause massive amounts of sediment to be transported into a near shore region. Tropical Storms Agnes (1972) and Eloise (1975) were responsible for transporting approximately 10 years worth of sediments into the Chesapeake Bay. This sediment transport was of the entire watershed, approximately 40 million tons of sediment (Langland and Cronin, 2003). Numerous studies such as Tonkin S. et al. (2003) and Jaffe B.E., and Gelfenbuam, G.A. (2007) have been conducted on sediment transfer during runup and drawdown of a tsunami. Many of these studies have been made post 2006. The studies indicate that these types of anomalies can drastically alter the seafloor during and after passage.

These factors also contribute to the second condition in the model that accounts for the route's vicinity to land. The increase in amount of additional clutter alone would cause the model to generate a resurvey now. Accounting for this type of anomaly between surveys, thereby reducing the weight of both burial and clutter, allows the model to give a more correct estimation of when to resurvey.

IV. METHOD

The idea for the Re-survey Integration Model (RIM) was derived from the CNMOC Battlespace on Demand (Linking Forecasts to Decisions) concept. This concept was created by the Commander, Naval Meteorology and Oceanography Command (CNMOC) and serves as a logical route by which survey data can be collected, statistically analyzed, normalized and calculated to produce an estimation of how often a resurvey should be conducted. Figure 7, similar to the CNMOC Battlespace on Demand slide, shows the path of data becoming a decision recommendation for commanders regarding survey periodicity.

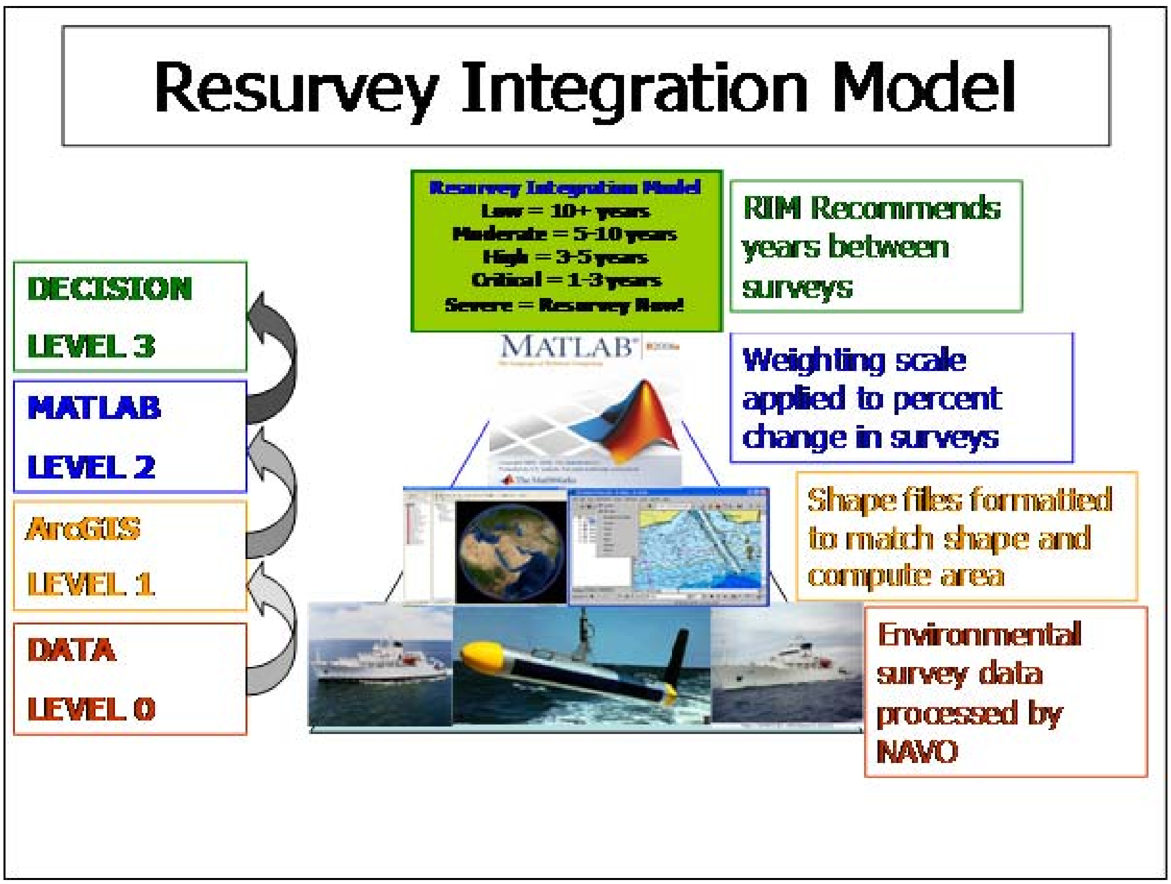

Figure 7. Resurvey Integration Model taken from CNMOC slide

Just as data flows in to the bottom of the pyramid in the CNMOC slide, so does the survey data provided by survey ships. NAVOCEANO has technicians who are trained to call contacts, assess roughness, determine burial and designate bottom sediments in order to determine bottom types. The four key parameters can be drawn from this data and compared with data obtained from a different survey of the same area. It is then possible to statistically calculate the percent change between the two surveys. This information can then be put into a model created with MATLAB, which will prescribe a resurvey index number corresponding to a resurvey periodicity recommendation.

A. THEORY

Let the horizontal coordinates be represented by (x, y) and the ocean bottom environment be represented by several categorical variables,

$$S^{(n)} = S^{(n)}(x, y), \quad n = 1, 2, ..., N, \tag{1}$$

with categories $\{s_1^{(n)}, s_2^{(n)}, ..., s_{I_n}^{(n)}\}$. For example, in mine detection, the four variables (or parameters) are very important: burial ($S^{(1)}$) with categories (1, 2, 3, 4, 5) (see Table 1), clutter ($S^{(2)}$) with categories (low, medium, high) (see Table 2), roughness ($S^{(3)}$) with categories (smooth, moderate, rough) (see Table 3), and sediments ($S^{(4)}$) with categories (mud, sand, rock) (see Table 4).

For an area of interest, the probability density function (PDF) of the variable $S^{(n)}$

$$P_i^n = P(S^{(n)} = s_i^{(n)}), \tag{2}$$

can be calculated from the survey. The bottom environmental change between two surveys is represented by the change of PDF, ΔP_i^n.

Effect of a bottom environmental variable ($S^{(n)}$) on mine detection is represented by an index ($\sigma^{(n)}$). Since temporal change in different categories leads to different effect, a resurvey index ($\Delta\sigma^{(n)}$) is defined by

$$\Delta\sigma^{(n)} = \sum_{i=1}^{I_n} \mu_i^{(n)} \Delta P_i^n / \sum_{i=1}^{I_n} \mu_i^{(n)} + \delta\sigma^{(n)}, \quad n = 1, 2, ..., N, \tag{3}$$

where $\mu_i^{(n)}$ are the weights of category $s_i^{(n)}$, and $\delta\sigma^{(n)}$ are the effects of other parameters on the resurvey index such as vessel traffic, hurricane passing by, and fishing density. A total resurvey index is defined by

$$\Delta\sigma = \sum_{n=1}^{N} w^{(n)} \Delta\sigma^{(n)}, \quad \sum_{n=1}^{N} w^{(n)} = 1. \tag{4}$$

Here, $w^{(n)}$ represents the importance of the environmental variable ($S^{(n)}$) on mine detection.

The survey periodicity is determined by the value of $\Delta\sigma$ using Table 6.

1. Selection of Periodicity Intervals

The range, description and periodicity recommendations in Table 6 are a compilation of data from NAVOCEANO, the UKHO model and the authors own MIW resurvey experience.

As stated above, both the U.S. and UK have been working on programs to predict survey periodicity. The determination of intervals between surveys is purely a recommendation based on scientific data. The science of selecting an appropriate periodicity interval is not exact; however, reasonable conservative estimates can be deduced based on the rate of change noted.

The two countries have developed similar programs and survey periodicity guidance. The RIM bases its interval selections on a combination of both the U.S. and UK models. However, the RIM intervals are more precise in that they attempt to narrow in on specific environmental changes that may fluctuate from each location.

The UK model's range is first based on whether the route is a Priority 1 or a Priority 2 survey. Priority 1 survey intervals are of shorter duration (i.e., resurveyed on a more frequent timeline) than Priority 2. When considering a Priority 1 survey interval, the lowest recommended interval for the highest percent change is 3–5 years (Armishaw, 2005).

Recommended resurvey intervals for priority 1 and priority 2 routes based upon the degree of seabed change.

Category	Seabed Changeability	Priority 1 Survey Interval	Priority 2 Survey Interval
1	HIGH	3-5 yrs	10-12 yrs
2	MODERATE-HIGH	5-7 yrs	12-15 yrs
3	LOW-MODERATE	7-10 yrs	15-20 yrs
4	LOW	10-15 yrs	20 yrs

Table 5. UKHO Model Survey Intervals (From Armishaw, 2005)

There are certain locations where the environmental or anthropogenic changes are occurring at a pace that would necessitate a smaller survey interval. Take Port Phillip Bay, Australia for example, Currie and Parry (1996) studied and determined the recovery time for the seafloor after scallop dredging was conducted. Their conclusion was that after only 11 months the seafloor ridges had returned to the flattened area caused by the dredge (Lokkeborg, 2005). The sediment type and near bottom currents in this region allowed for an environmentally "quick" recovery period. In some cases, a 1–3 year interval will be necessary or depending on the last current survey date, a "resurvey now" will be required. The additional ranges in the UK model seem to be adequate based on the amount of change occurring.

NAVOCEANO has also produced metrics to help facilitate recommendations for route survey periodicity. The survey periodicity guidance created by NAVOCEANO also has a three-year interval as its lowest recommended survey interval for what it considers Fast Relative Rate of Change (CNMOC, 2007). An example of the NAVOCEANO metrics can be seen in Figure 8.

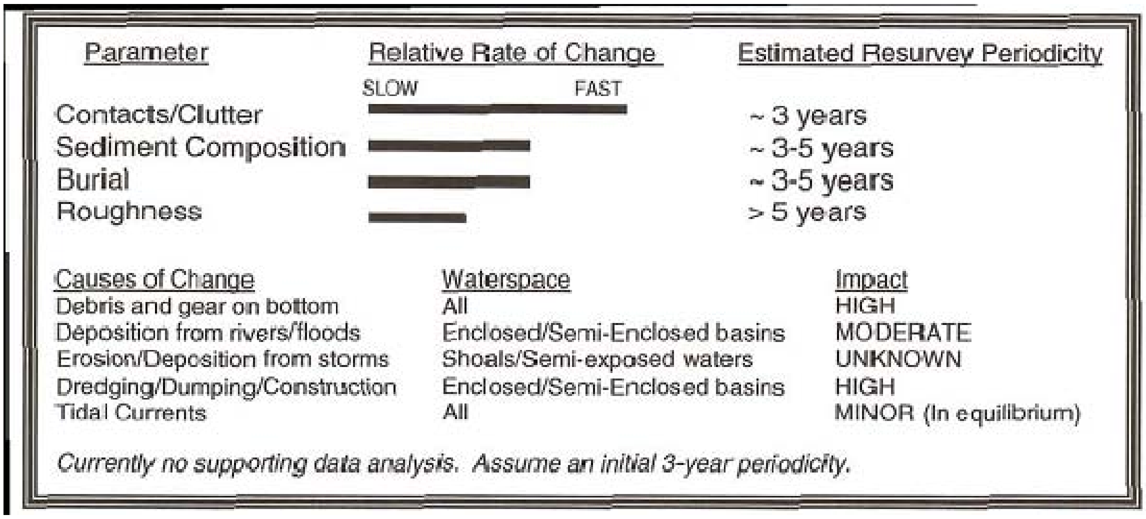

Figure 8. CNMOC/NAVOCEANO Parameters, Relative Rate of Change and Periodicity guidance (From CNMOC, 2007)

As stated above, the survey area may have conditions that require a smaller interval. It is also important to note that the conditions of the seafloor may not be the sole consideration for survey periodicity recommendations. A smaller interval may be dictated by a deteriorating or threatening geopolitical situation. Please see the classified appendix for further information.

The Resurvey Index Guide (see Table 6), designed for the Resurvey Integration Model, captures a more realistic periodicity range by combining the resurvey periodicities recommendations from NAVOCEANO’s metrics and the UKHO’s Route Resurvey Model. Additionally, modifications have been made as a result of the authors MIW survey experience to presents a more gradual range ($\Delta\sigma$) of recommendations in order to better represent environmental changes between surveys.

Resurvey Index Guide		
INDEX RANGE	DESCRIPTION	RECOMMENDATION
< 0.20	Low	10+ Years
0.20–0.40	Moderate	5–10 Years
0.40–0.60	High	3–5 Years
0.60–0.80	Critical	1–3 Years
> 0.80	Severe	Re-survey Now

Table 6. Determination of survey periodicity using the increment of the resurvey index.

Table 6 coordinates the calculated final resurvey index number ($\Delta\sigma$) with the corresponding periodicity recommendation. The selection of ranges is based on a percent change in total above the original summed index value of the four parameters. So <0.20 Low equates to a range that is within 20% of the original index value. >0.80 means 80% or higher percent change over the original index value. This Resurvey Index Guide will aid commanders deciding on which areas to allocate limited, but necessary, resources based on the calculated periodicity recommendation.

Determination of $w^{(n)}$ becomes one of, if not the most critical, determination of this model. This model initially uses

$$w^{(1)} = w^{(2)} = w^{(3)} = 0.3, \quad w^{(4)} = 0.1. \tag{5}$$

The sediment has a lower value because the composition of the bottom sediments does not change substantially over the same period of time as the other three variables. Generally, burial, clutter and roughness will change the greatest amount over the period of time between surveys. These three variables contribute the most to the overall changes in the seafloor environment and thus, have a higher initial value.

a. Geopolitical (Nonscientific) Reason for Shorter Duration Survey Periodicity

Please see the classified special appendix for further information.

2. Determination of Weighting Requirements

For a particular variable $S^{(n)}$, the weights for each category $\mu_i^{(n)}$ are predetermined as shown in Table 7.

Category	$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(4)}$
1	1.0	1.0	1.0	2.0
2	1.0	1.5	1.5	2.0
3	1.5	3.0	3.0	1.0
4	3.0			
5	4.0			

Table 7. Weights ($\mu_i^{(n)}$) for each category in the four key parameters ($S^{(n)}$).

Each $\mu_i^{(n)}$ was determined for the four key parameters based on amount of effort involved in conducting MIW hunting and clearing operations. The more challenging the category for MIW operators, the more weight that is applied to that specific category. This calculation requires the RIM user to input a negative sign if the percent change in a category is reduced. If the percent change is a gain, then a positive value is entered. Figure 7 depicts a basic diagram for better understanding the method for each categories weightfor $\mu_i^{(n)}$!

Figure 9 illustrates the weighting scheme derived for the RIM.

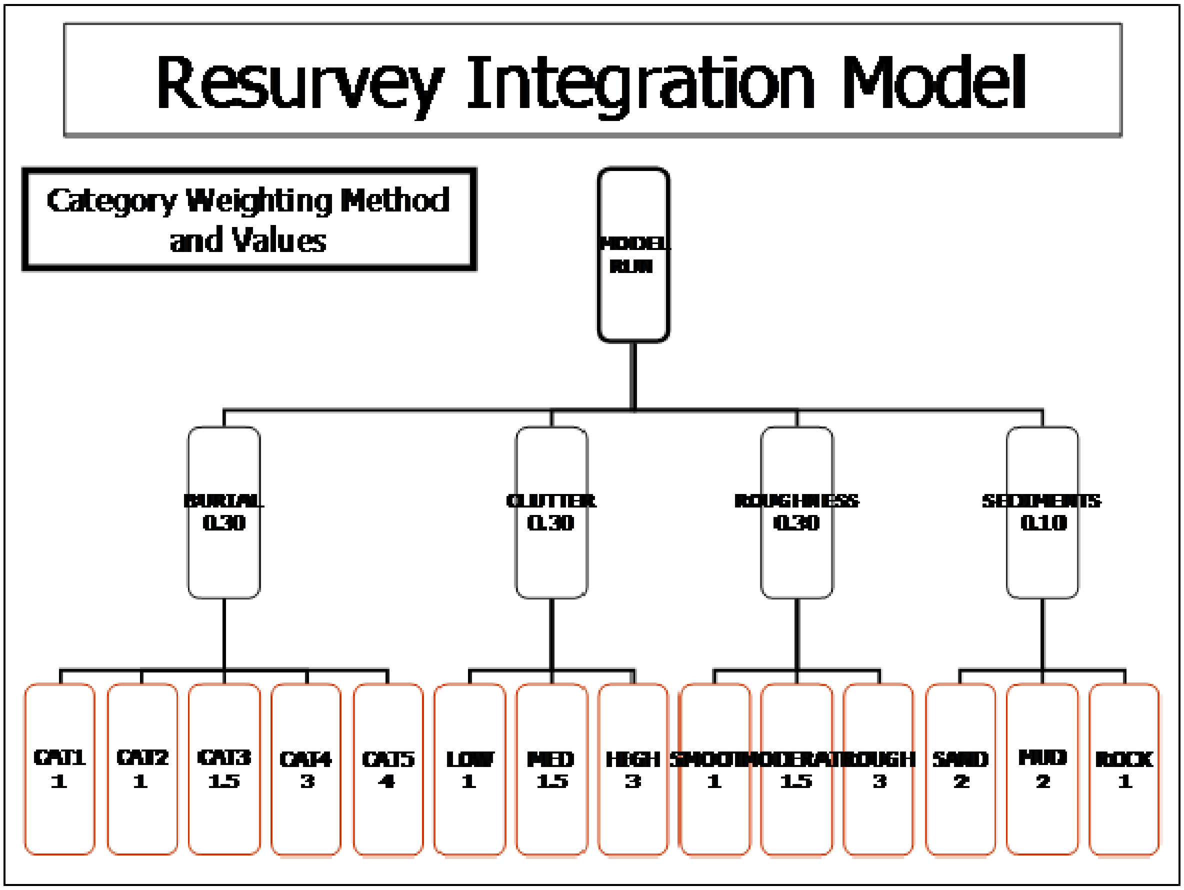

Figure 9. RIM Weighting Scheme

The first key parameter is burial and it has five internal categories, as shown in Chapter III. The first two categories of **0%** and **0–10%** do not contribute to the complication of an area so each is weighted at one times the percent change. The third category of **10–20%** begins to become more difficult for MIW assets to detect and classify so it is weighted at one and a half times the percent change. The forth and fifth categories, **20–75%** and **75–100%** have the most effect on MIW operations and are weighted at three and four times, respectfully, the percent change. If these two categories increase or decrease, it will either help or hinder the MIW effort.

The second key parameter of clutter has three internal categories. The range is from low to high clutter. The weight applied to **low** clutter is one times the percent change. The second category is **medium,** and it is weighted at one and a half times the

percent change. The third category is **high,** and it is weighted at three times the percent change. Similar to that of burial, the more significant impact to MIW operations will occur in the medium to high range of clutter.

The third key parameter is roughness, and it also has three internal categories. The first is **smooth** and is weighted at one times the percent change in smooth roughness. The second is **moderate** which has associated with a weight of one and a half times the percent change. The final category is **rough,** and it has a weight value of three times the percent change.

The final parameter is sediments, which tend to remain similar with little or no change between reasonable survey periods. In the NAVOCEANO Guide, Appendix E lists the MIW Standard Categories. Using this list, it is possible to make an estimate of percent change of general categories from Rock, Mud and Sand. Typical changes of less than approximately 5% are considered negligible by the RIM. The categories of Mud and Sand tend to be the most challenging for MIW operations and; therefore, each has a weighted value of two times the percent change. The Rock category is of less significance in hindering MIW detection and classification and therefore is only weighted at one time the percent change.

Figure 10 incorporates the entire process of the RIM. It illustrates the exchange from basic survey data into a recommendation regarding survey periodicity. Each level in the figure is color coded to designate which portion of the pyramid (Figure 7) the step corresponds. The outlined boxes express what percent changes are being used to modify the original index number of the four parameters (i.e., Burial, Clutter and Roughness at 0.30 and Sediments at 0.10).

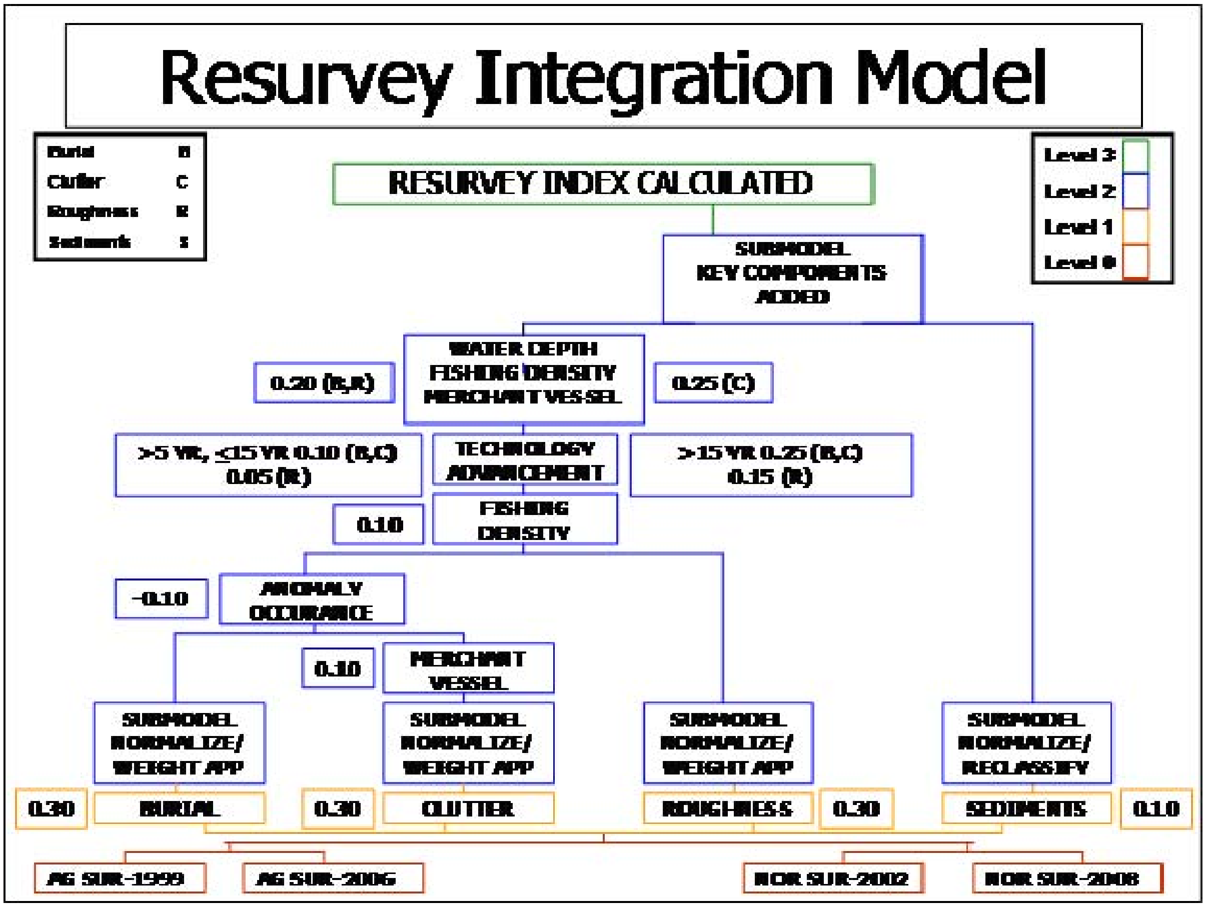

Figure 10. RIM Design Path

B. PROGRAMS

1. ArcGIS

The initial data obtained from NAVOCEANO is in the form of shape files that can be viewed and manipulated in ArcGIS. This program provides several tool options to depict the data for use in the RIM. It is absolutely necessary to understand and use ArcGIS in order to gain the information needed by the RIM.

2. MATLAB

MATLAB was chosen to produce a useable model based on it's mathematical foundation. Data extracted from ArcGIS, and compared to calculate percent change, can

easily be entered into the RIM. MATLAB would then conduct all calculations and produce a resurvey index number and recommended resurvey periodicity.

3. Historical Temporal Shipping (HITS) Database

This database is supported by NAVOCEANO and runs a model that bases its knowledge on data received from the Lloyds of London. From 1998, 1999 and 2000, the harbor and ship (deck) logs were studied to give an estimate of the ship route prior to entering port. This information was used to determine common routes used by ships and provide a density calculation for those areas. Additional information needed for the MATLAB model would be on this HITS database.

The information provided can be useful in MIW planning, but its scope is limited. The HITS database has five categories: 1-Super Tanker, 2-Large Tanker, 3-Merchant, 4-Tanker, 5-Fishing. This breakdown provides insight into which types of ships have higher densities in the area of interest. This model provides the operator knowledge on average vessel and fishing densities in the area of comparison. If the average densities are high, the model will give insight into the chance of increased burial, clutter or roughness. This model is run by NAVOCEANO and compiles the information into the Oceanographic and Atmospheric Master Library (OAML) database.

C. DATA COLLECTION

Data collection for this thesis was conducted by NAVOCEANO and NOAA survey vessels. The Norfolk route data was collected by NOAA to support a DHS requirement.

The USNS HENSON and USNS KANE collected the data for the AG route. More information can be found in the Classified Appendix regarding this data set.

D. DATA MANIPULATION

The data used for this thesis was derived and compiled by NAVOCEANO. NAVOCEANO, using ArcGIS, provided shape files that included data tables showing burial, clutter, roughness, and sediments. These files corresponded to various surveys that were conducted previously.

The survey data had to first be geo-referenced as it shows up without a spatial reference. Using the data management tools, the projection was defined under the Geographic Coordinate System as World Geodetic System 1984 (WGS84). It was necessary to convert the projection into a format in which area could be determined. This required converting or re-projecting the data into a Mercator projection to allow for a linear unit of meters. From this, it was possible to calculate square meters, and in turn square kilometers, in order to obtain area measurements from the data. Prior to the area comparisons, the two surveys had to be "clipped" to match one another in size and shape. The user can then calculate for comparison, square meter (kilometer) regions and generate statistical values of each of the four key parameters.

E. RESURVEY INTEGRATION MODEL (RIM)

Typically, the first step to using any model is inputting the data obtained by the user. For the resurvey model, it is first necessary to process the data in ArcGIS and then calculate percent change in area by subset in each category of the four key parameters before running the model. The model is designed for the user to input these percent changes by hand.

The model will ask for a series of inputs by the user. It is important that the user follows the provided guidance concerning the format the input data should be entered. For example, if the change in Low Clutter is a **gain** of **25%** then the user should input **25**. If the change in Low Clutter was a **reduction** of **25%** then the user should input **-25**.

The model begins by asking the user to input the current year. Next, it asks for the date (year only) of the most current survey followed by entering the date of the most current previous survey. This information is critical in determining if any subset weights need to be applied to the calculation. This concept is used to keep a long survey period with substantial changes separate from a short survey period with substantial changes and to account for when the last survey occurred. For example, a survey period of 18 years with substantial changes and a most current survey a year prior. Without the submodel calculation, this condition may generate a "resurvey now," which may not be necessary. Comparing this condition with one in which the most current survey was several years

ago would be acceptable for the “resurvey now” solution. The goal is for the model to understand whether there has been a “recent” most recent survey or a “long ago” most recent survey and to understand the difference between a high percent change over a short period verses a high-percent change over a long duration.

The next input requests a user to identify if there has been an uncommon anomaly (hurricane/cyclone or large scale tsunami) impacting the area during the period between surveys. For a hurricane, if the eye passed within 50 nautical miles of the location during the period between surveys. For a tsunami, if the waves directly passed over the area of interest. A ‘yes’ answer will then prompt the program to request whether the location is within five nautical miles of land. Why these two inputs are important is depicted in Chapter III. A hurricane or tsunami passing over the location could generate environmental conditions not generally associated with the area, which could greatly impact the burial parameter. If the location is within 5 miles of land, the clutter parameter could have a much higher change then normal. If not accounted for, the model will generate a higher resurvey requirement than would be necessary. If both conditions are met, the result is a reduction of both burial and clutter by 10% each. This reduction will help to eliminate false high resurvey requirement recommendations.

The model then requests the percent change per category in the parameters of burial, clutter, roughness and sediments. The percent change input is then multiplied by the weighting value of the particular category. Once each category has been multiplied with the weighting value, it is then summed and divided by the sum of the weighting values. The calculation for weight normalization of each parameter is noted below.

This process allows for weight to be applied based on comparison data to the various categories in each parameter. This process is known as normalizing the data field for each of the four parameters. It then maintains the balance of weight for the overall parameters. Once these calculations are made, they are then divided by 100 and added to their respective parameter’s overall index number.

The program then requests the maximum water depth, in meters, of the survey area. This allows the program to determine if the area is shallow enough to be in danger of both bottom mines and moored mines. This particular step is addressed more closely in the classified appendix.

The last two inputs are for yearly merchant vessel densities and yearly fishing vessel densities. This step requires the user to determine the average yearly density of these two categories for the years between surveys. If the merchant vessel traffic is greater than or equal to 2000 ships, a 10% weight is added to the clutter parameter. As the density of ships passing over a survey area increases, so does the chance for debris getting tossed over the side. The LA/Long Beach harbor recorded 6,087 arrivals during 2006. This number was determined by the Marine Exchange. This is an extremely busy port and ranks #5 behind Shenzhen, with Singapore ranking #1, just slightly above Hong Kong (Seaports Press Review, 2009). By taking into account the worlds busiest ports, it can be arguably determined that one-third of the vessel traffic of the LA/Long Beach harbor would be a considerable amount of traffic to pass over an area. This is why the model uses 2000 as a break between high and low density for merchant vessels.

For fishing densities greater than or equal to 120, the program will add an additional 10% weight to burial, clutter and roughness. This number is based on 10 fishing vessels a month impacting the seafloor per year.

There is also a special category that ties water depth, fishing density and merchant density together to produce an added weight to burial, clutter and roughness. This category tries to encompass the effects of high density traffic and shallow water to better describe busy ports or harbors. The variables needed to meet or exceed this category would be rarely encountered, but provides the model with the ability to be used around the globe. If the water depth is 200 meters or less, the fishing density is greater than or equal to 240 and the merchant vessel density is greater than or equal to 4000 then the burial and roughness have an additional 20% and clutter receives an additional 25%.

F. RIM MATLAB PROGRAM

```
% Model Name:        Resurvey Integration Model
% Model Title:       rim
%
% Original Code by:    H. F. Coke, V
%                      LCDR    USN
%
% Thesis Advisor:     Professor Peter Chu
%
% Date Written:       July 2009
% NPS Thesis Requirement
% Route Survey Periodicity for Mine Warfare
%
% Model Security
% Classification:     Unclassified
%
% Purpose:
%
%      This program was written to calculate resurvey periodicities based
%      on data input.  The model requires the input of several key factors
%      produced by the Naval Oceanographic Office to determine when a
%      resurvey of a harbor or route should be completed.

clear all;
close all;


% Initial Index value W(n) (S(n))


Wb = 0.30;
Wc = 0.30;
Wr = 0.30;
Ws = 0.10;

Date = input('Enter current year (i.e., 2009):    ');
A = input('Year of most current survey (example 2009):    ');
B = input('Year of survey prior to most current survey (example 2006):    ');
% Determination of anomaly during survey periods
anom = input('Did a hurricane/cyclone or tsunami pass within 50 nm of location
during period? (yes or no)):    ','s');
if strcmp(anom, 'yes')
   prox = input('Is location within 5 nm of shoreline? (yes or no)):    ','s');
end

% Burial
```

```
C1 = input('Percent change in Burial Cat 1 (i.e., gain = 50 or reduction = -50):
');
C2 = input('Percent change in Burial Cat 2:    ');
C3 = input('Percent change in Burial Cat 3:    ');
C4 = input('Percent change in Burial Cat 4:    ');
C5 = input('Percent change in Burial Cat 5:    ');

%  Clutter
D1 = input('Percent change in Low Clutter:    ');
D2 = input('Percent change in Medium Clutter:    ');
D3 = input('Percent change in High Clutter:    ');

%  Roughness
E1 = input('Percent change in Smooth Roughness:    ');
E2 = input('Percent change in Moderate Roughness:    ');
E3 = input('Percent change in Rough Roughness:    ');

%  Sediment
F1 = input('Percent change in Mud Sediment category:    ');
F2 = input('Percent change in Sand Sediment category:    ');
F3 = input('Percent change in Rock Sediment category:    ');

%  Water Depth
G = input('Max Water Depth of survey area (meters):    ');

%  Merchant Vessel and Fishing Vessel Densities
merden = input('Average Yearly Merchant Vessel Density for period between
surveys:    ');
fishden = input('Average Yearly Fishing Vessel Density for period between
surveys:    ');

if(isempty(C1)), C1=0; end
if(isempty(C2)), C2=0; end
if(isempty(C3)), C3=0; end
if(isempty(C4)), C4=0; end
if(isempty(C5)), C5=0; end

if(isempty(D1)), D1=0; end
if(isempty(D2)), D2=0; end
if(isempty(D3)), D3=0; end

if(isempty(E1)), E1=0; end
if(isempty(E2)), E2=0; end
if(isempty(E3)), E3=0; end
if(isempty(F1)), F1=0; end
```

```
if(isempty(F2)), F2=0; end

if(isempty(merden)), merden=0; end
if(isempty(fishden)), fishden=0; end

year = A - B;  % Determines years between survey dat

C = [C1, C2, C3, C4, C5];  %  Burial category inputs
CW = [1, 1, 1.5, 3, 4];  %  Weights applied to Burial category input (w^(n))
CWN = sum(C.*CW)/sum(CW);  %  Normalizes the Burial categories
Wb = Wb + (CWN/100);     %  Accounts for reduction or gain in categories of Burial (Higher burial = more weight)

D = [D1, D2, D3];  %  Clutter category inputs
DW = [1, 1.5, 3];  %  Higher clutter will make MIW Ops more challenging input (w^(n))
DWN = sum(D.*DW)/sum(DW);  %  Normalizes the Clutter categories
Wc = Wc + (DWN/100);  %  Accounts for reduction or gain in categories of Clutter

E = [E1, E2, E3];  %  Roughness category inputs
EW = [1, 1.5, 3];  %  Higher roughness makes MIW Ops more challenging input (w^(n))
EWN = sum(E.*EW)/sum(EW);  %  Normalizes the Roughness categories
Wr = Wr + (EWN/100);  %  Accounts for reduction or gain in categories of Roughness

F = [F1, F2, F3];  %  Sediment category input
FW = [2, 2, 1];  %  Weighting = category shifts in sediment input (w^(n))
FWN = sum(F.*FW)/sum(FW);  %  Normalizes the Sediment categories
Ws = Ws + (FWN/100);  %  Accounts for reduction or gain in categories of Sediments

W = [Wb,Wc,Wr,Ws];  %  Puts 4 parameters into a strm

%  Effect of other variables on each parameters weighting (δσ^(n)) and their specific weights (μ_i^(n))

if strcmp(anom, 'yes') & strcmp(prox, 'yes');   %  Accounts for hurricane or cyclone
   W(1) = W(1) - 0.10;       %  in close proximity to shore
   W(2) = W(2) - 0.10;
end;

if merden >= 2000;  %  Accounts for high vessel densities
```

```
    W(2) = W(2) + 0.10;
end;

if fishden >= 120; %  Accounts for high fishing densities
    W(1) = W(1) + 0.10;
    W(2) = W(2) + 0.10;
    W(3) = W(3) + 0.10;
end;

if year > 5 & year <= 15;    %  Accounts for technological improvements
    W(1) = W(1) + 0.10;
    W(2) = W(2) + 0.10;
    W(3) = W(3) + 0.05;
elseif year > 15;  %  Accounts for excessive amounts of time between surveys
    W(1) = W(1) + 0.25;
    W(2) = W(2) + 0.25;
    W(3) = W(3) + 0.15;
end;

if G <= 200 & fishden >= 240 & merden >= 4000;  %  Accounts for shallow
water and high fishing and merchant traffic
    W(1) = W(1) + 0.20;
    W(2) = W(2) + 0.25;
    W(3) = W(3) + 0.20;
end

if G > 900
    disp('Water depth too deep for current mine threats, no resurvey required');  %
Accounts for water depth too deep for mission abort damage
else

    disp('W values')
    disp(W);

%     W=W/sum(W);  %  Normalizing the four parameters back equal to 1

end;

V = Date - A;  %  Accounts for years between current date and last survey
Z = V ./ year;  %  Develops ratio of years since last survey and number of years
between surveys
                %  This is to account for a great deal of change over a
                %  longer period and a much less amount of time since last
                %  survey and today's date.
```

```
% Resurvey Index (σ^(n))
x = sum(W) - 1;
   disp('Resurvey Index is')
   disp(x)

   if x <= 0.2000;
      disp('Low (10+ years)')

   elseif x <= 0.4000;
      disp('Moderate (5-10 years)')

   elseif x <= 0.6000;
      disp('High (3-5 years)')

   elseif x <= 0.8000;
      disp('Critical (1-3 years)')

   elseif Z >= 0.4000;
      disp('Severe (Resurvey now!)')
   else
      disp('High (3-5 years)')
   end
```

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V. RESULTS

During this experiment, the Norfolk and AG survey comparisons yield different resurvey index calculations after being processed by the RIM. The **AG survey** has a resurvey index of **0.1718** corresponding to a **Low (10+ years)** resurvey recommendation. The **Norfolk survey** RIM run has an index of **0.5791** implying a **High (3–5 years)** resurvey recommendation. This outcome makes sense as the two survey comparisons have varying percentage outcomes in each of the four key parameters.

Upon further examination of the two data sets, it is clear that the Norfolk data has an exceptionally large increase in clutter between the two survey periods. This accounts for a larger weighted clutter category which supports the model's calculation of a higher resurvey index and lower periodicity recommendation (Shorter time interval).

In contrast, the AG survey comparison has an increase of only 29% in the high clutter category. The AG also has a significant reduction in the highest roughness category. By taking both clutter and roughness percent change into account, the model reduces the resurvey index and thus, recommends a higher resurvey periodicity (Longer time interval).

All other parameters are of negligible difference between the two survey locations. The years between surveys are only different by one year and the maximum water depths are similar as well. The large increase in clutter in the Norfolk area drives the model to recommend a survey periodicity that is more often than in the AG area. The 83% increase in clutter at the Norfolk location will cause a greater challenge for conducting MIW operations in the area. Due to the high percent change in clutter, the model is correct in predicting a shorter (higher frequency) survey interval. Therefore, if a mining event occurs, ports and harbors could be cleared and open with greater efficiency. Please see Tables 8 and 9 for input values and resurvey index calculations.

RIM Run For AG

Enter current year (i.e., 2009): 2009

Year of most current survey (example 2009): 2006

Year of survey prior to most current survey (example 2006): 1999

Did a hurricane or cyclone pass within 50 nm of location during period? (yes or no)): no

Percent change in Burial Cat 1 (i.e., gain = 50 or reduction = -50): 0

Percent change in Burial Cat 2: 2

Percent change in Burial Cat 3: -2

Percent change in Burial Cat 4: 0

Percent change in Burial Cat 5: 0

Percent change in Low Clutter: -36

Percent change in Medium Clutter: 7

Percent change in High Clutter: 29

Percent change in Smooth Roughness: 1

Percent change in Moderate Roughness: 50

Percent change in Rough Roughness: -60

Percent change in Mud Sediment category: 0

Percent change in Sand Sediment category: 0

Percent change in Rock Sediment category: 0

Max Water Depth of survey area (meters): 120

Average Yearly Merchant Vessel Density for period between surveys: 120

Average Yearly Fishing Vessel Density for period between surveys: 0

W values

0.3990 0.5118 0.1609 0.1000

Resurvey Index is

0.1718

Low (10+ years)

Table 8. Input values and generated index for AG

RIM Run For Norfolk

Enter current year (i.e., 2009): 2009

Year of most current survey (example 2009): 2008

Year of survey prior to most current survey (example 2006): 2002

Did a hurricane or cyclone pass within 50 nm of location during period? (yes or no)): no

Percent change in Burial Cat 1 (i.e., gain = 50 or reduction = -50): 0

Percent change in Burial Cat 2: 0

Percent change in Burial Cat 3: 0

Percent change in Burial Cat 4: 0

Percent change in Burial Cat 5: 0

Percent change in Low Clutter: -83

Percent change in Medium Clutter: 0

Percent change in High Clutter: 83

Percent change in Smooth Roughness: -15

Percent change in Moderate Roughness: 10

Percent change in Rough Roughness: 5

Percent change in Mud Sediment category: 0

Percent change in Sand Sediment category: 0

Percent change in Rock Sediment category: 0

Max Water Depth of survey area (meters): 25

Average Yearly Merchant Vessel Density for period between surveys: 10

Average Yearly Fishing Vessel Density for period between surveys: 0

W values

0.4000 0.7018 0.3773 0.1000

Resurvey Index is

0.5791

High (3-5 years)

Table 9. Input values and generated index for Norfolk

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VI. RECOMMENDATIONS

The RIM attempts to incorporate all reasonable variability to present a periodicity index recommendation. As with most models, it will only run to the quality of the data being supplied. The more intelligence about a given area, the more exact the output can be determined.

In the process of creating this model, there were several broad variables noted that, if more specifically defined, would produce a stronger resurvey periodicity recommendation. The HITS model does not provide sufficient data as to what type of fishing vessels may be conducting operations in the area of interest. Categorizing the wide variations in fishing techniques (i.e., Trawling verses Trolling) that greatly impact the seafloor would provide greater insight and strengthen the final recommendation. In addition, knowing the per year average of dredges and trawlers operating in the vicinity of a harbor or route would also benefit the output of the model. Due to the limited temporal data provided by the HITS model, it would be impossible to note any current trends in shipping or fishing route variations.

The RIM can be further enhanced and verified with the addition of a greater variance of survey data comparisons. This process will help to refine the resurvey index value. NAVOCEANO and NOAA have conducted numerous surveys in various regions around the U.S. and globe. Obtaining this data takes time, but would be worthy of applying the model to predict periodicity. Continuous and consistent evaluation is the best way to maintain a properly working model.

A. FUTURE WORK

As with any simulation model, work must be done to continually improve the process. The RIM will require additional data comparisons. It is not unreasonable for slight adjustments to be made with the weighting scales as more and more comparisons are processed. As additional data becomes available for areas where the environmental characteristics vary substantially, the model will produce a more precise

recommendation. The RIM will allow for additional survey comparisons to be conducted, which will continue to improve the accuracy of the model.

It also would be note worthy to point out the advantage of utilizing the analogous area concept with output from the RIM. Areas with only one survey could be compared to other areas with multiple surveys based on environmental similarities. This could help alleviate the need to conduct multiple surveys of numerous areas thereby saving time and resources.

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